THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

ISSN 1822-427X print / ISSN 1822-4288 online
2014 Volume 9(1): 26–30

APPLICATION OF DESIGN SPEED FOR URBAN ROAD AND STREET NETWORK

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Abstract. Building of arterials in densely populated urban areas needs significant financial expenses. In the situation when the available financial resources for street and bridge construction are limited, the most important issue is to evaluate all possible ways to reduce the total road construction costs what is first of all achieved by reducing geometrical parameters of arterials. These parameters are reduced by changing the design speed, while ensuring an adequate level of traffic safety. Therefore there is a need for a review of standards for the street functions and categories of streets in urban areas. An analysis of average momentary speed impact on urban street and road network design, as well as momentary speed impact on traffic conditions has been done. A relationship between design speed and momentary speed at different capacity ratio of traffic flow has been found.

Keywords: design speed, local speed, momentary speed, traffic flow density, level of traffic load.

1. Introduction

The construction of modern new arterial streets in densely populated urban areas requires very significant capital investments that are connected with the demolition of the existing housing, relocation of businesses, relocation of population to other areas, expropriation of land, reconstruction of utilities, etc. (Melo *et al.* 2013). When the financing for street construction becomes very limited the issue of possible reduction in the road construction costs becomes very topical (Anas, Hiramatsu 2012). Firstly, it is achieved by reducing the design speed on arterials. At the same time it has to be duly noted that the reduction of geometrical parameters never leave negative impact on the level of traffic safety (Lazda, Smirnovs 2009; Matírnez *et al.* 2013).

In urban street network a well-considered management of traffic flow becomes more and more important and it is not implemented in good quality if the interrelations among the factors that characterise the existing transport flow are not known (Nitzsche, Tscharaktschiew 2013). Traffic volume and consequently the loading of streets have changed considerably in the recent years, as is also mentioned by Brilon (2010). The aim of this study is to evaluate the indicators of traffic flow on arterials in the urban street network with free traffic flow. To achieve this aim it is necessary to determine the interrelations of momentary speed, traffic volume and traffic flow density (Islam *et al.* 2014). In addition to that it is necessary to perform analysis on the arterials with free traffic flow in urban areas with different number of lanes, different speed limits and at different conditions of level of traffic load (De Luca *et al.* 2012). Finally, the interrelation between design speed and 95% momentary speed at different level of traffic load has to be determined.

2. Research methodology

The applied methodology is based on the measurement of momentary speed and traffic volume data on arterials with free traffic flow in the urban street network (Camacho-Torregrosa *et al.* 2013). The measurements were recorded on two carriageway streets with two or three lanes in each direction that have different design speed. The measurements were recorded in different periods and at different traffic volume from 2007 until the end of 2009. Data recording was performed automatically with special counters and grouped per each hour during the day time (7 a.m.–8 p.m.) throughout the whole year. Reading of traffic data is done according to two types of measuring. The first type of measuring is done with induction loops installed in roadway pavement that register all vehicles moving along the arterial in both directions. The second type of measuring is done with laser beams where special laser system is installed on a special gantry located above lanes. Infrared sensors are installed above lanes in both directions (Castro *et al.* 2013).

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Processing and storing of measurements is done with special software that provides the possibility to review time diagram of each controlled sensor, as well as collection of general statistical data. Data array that is compiled throughout a day time is divided according to each day for each sensor and saved in a text file. The compiled data is transferred via GSM (Global System for Mobile communications) terminal to management centre for further processing and classification.

3. Research results

To acquire overview on average driving speeds on regulated arterials, speed measurements of vehicles in real traffic were performed. At the same time a number of data was recorded, such as the lengths of studied street sections, the number of lanes in these sections, travel time and regulation speed (Eluru *et al.* 2013). Measurements of traffic speeds showed that the average driving speed on regulated arterials of the Riga city in morning peak hours (7–9 a.m.) was approx 20 km/h in the locations where the maximum regulation speed was 50 km/h. At the same time the average driving speed on free-flow arterials with regulation speed of 70 km/h of the Riga city in morning peak hours (7–9 a.m.) was 50 km/h, which in comparison with regulated arterials was even twice as much. This is explained by the fact that there are no traffic lights on free-flow arterials (Archer *et al.* 2008).

Traffic volume on free-flow arterials changes throughout a day (Fig. 1). However, if some time ago more dense traffic was observed in certain morning and evening hours, the situation at present has changed. The results show that the peak of traffic flows is observed from 7 a.m. until 8 p.m. This leads to the conclusion that dense traffic flow is observed in more than a half of the 24 hours.

The speed of each vehicle at a specific moment of time is called momentary speed. The existing speed measurements on free-flow arterials were done according to the local measurement method. Therefore to perform further traffic analysis the speed data that was acquired automatically was transformed into average momentary speeds for all free-flow arterials with the help of the formula (Smirnovs 2008):

$$V_m = \frac{N}{\sum \frac{1}{V_l}}, \quad (1)$$

where V_m – average momentary speed, km/h; N – number of recorded vehicles, veh; V_l – local speed, km/h.

The analysis of acquired data on average momentary speeds leads to a conclusion that the existing speeds on free-flow arterials in very seldom cases exceeded the design speeds for traffic arterials. The driving speed that exceeds the design speed is actually recorded only during night time (8 p.m.–4 a.m.) that is only 20% of the whole day. Traffic volume in these hours is, of course, minimal. At the regulation speed of 50 km/h such situations is observed only in 2% of all hours per day. At the regulation speed of 70 km/h the situations when the driving speed has exceeded the design speed have occurred even more rarely – only in 0.03%.

Figs 2 and 3 show the distribution of average momentary speed in % in the existing traffic flow.

Based on the above mentioned a conclusion id made that enormous capital investments required to implement geometrical parameters of arterials streets set in the existing normative documents are in fact inadequate as they provide traffic safety only for 2% of drivers who in essence are deliberate violators of traffic regulations and brutally exceed the maximum regulation speed by more than 30 km/h.

3.2. Relations found

3.2.1. Traffic flow density and average momentary speed

The performed analysis shows that at level of traffic load of 0.2 to 0.4 the regulation speed is not affected. With the increase of traffic volume the average momentary speed

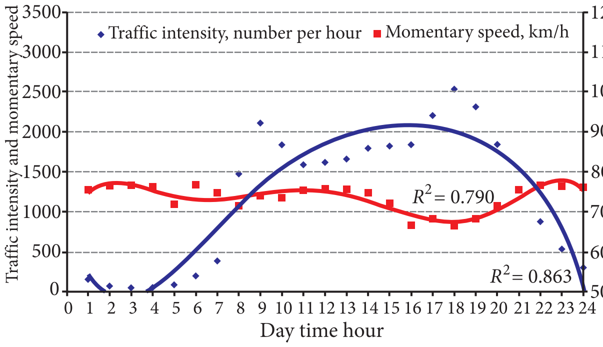

Fig. 1. Relation of traffic volume and momentary speed at regulation speed of 70 km/h

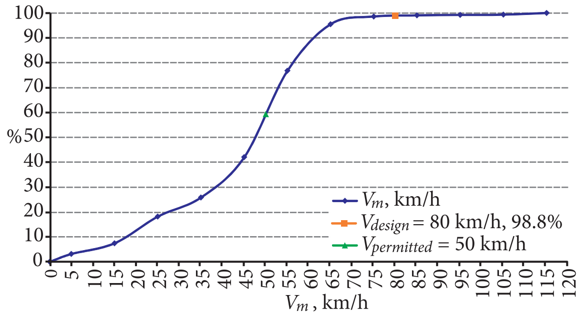

Fig. 2. Distribution of average momentary speed at regulation speed of 50 km/h

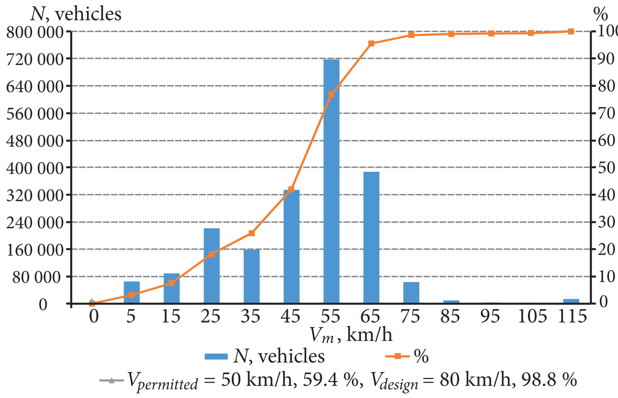

Fig. 3. Histogram of average momentary speed

decreases. When the traffic flow density is high and the loading factor is more than 0.8 the average momentary speed decreases and the traffic flow density increases. In the study a more stable relation is observed between driving speed and traffic flow density.

Traffic flow density was calculated:

$$C = \frac{Q}{V_m}, \quad (2)$$

where C – traffic flow density, vpkm (vehicle per kilometre); Q – traffic volume, vph (vehicle per hour); V_m – average momentary speed, km/h.

In changing weather conditions or because of accidents or vehicles parked on roadways, congestion situations occur when the driving speed decreases for 5–10 km/h and the traffic volume decreases, as well. The specified traffic conditions relate to maximum traffic volume and loading factor close to 1.0.

The determined relation of traffic flow density and driving speed allows forecast the average momentary speed on free-flow arterials if the traffic flow density is determined:

– at regulation speed of 70 km/h with 3 lanes:

$$V_m = 61.01 + 0.257C - 0.004C^2; \quad (3)$$

– at regulation speed of 70 km/h with 2 lanes:

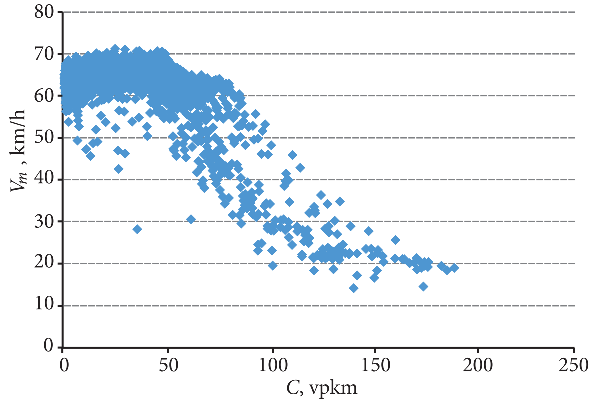

Fig. 4. Relation of 95% average momentary speed and traffic flow density

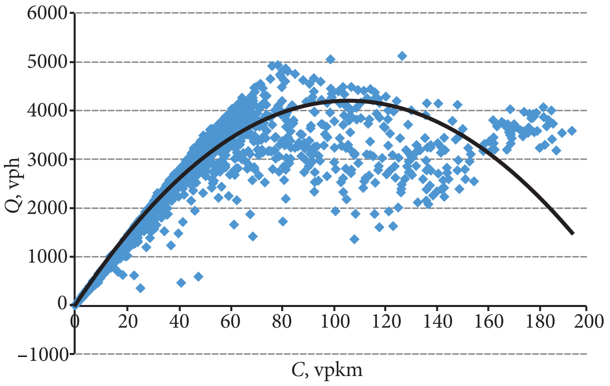

Fig. 5. Relation of traffic volume and traffic flow density

$$V_m = 53.28 + 0.535C - 0.012C^2. \quad (4)$$

The relation between traffic flow density and average momentary speed is also used to describe the conditions of traffic flow (Dhamaniya, Chandra 2013). Similarly to the relation between traffic volume and average momentary speed the existing speed in traffic low greatly depends on traffic flow density. The greater the number of vehicles in traffic, the lower is the existing speed. Fig. 4 shows the relations between traffic flow density and average momentary speed on arterial streets with free traffic flow at different regulation speed, as well as with different numbers of lanes in different time periods.

3.2.2. Traffic volume and traffic flow density

According to the reference (Brilon 1993) when determining road capacity it was assumed that the capacity of one lane is 2000 vehicles per lane. This means that the total capacity is calculated by multiplying the number of lanes with the capacity of one lane. However, there are serious obstacles in real traffic on free-flow arterials that reduce the total capacity of arterials significantly. Constant changing of lanes, overtaking and manoeuvring have to be considered. Therefore the total capacity is calculated by multiplying the capacity of a single lane with respective capacity adjustment factor α.

Data on traffic volume does not show the specific types of vehicles, therefore this data has to be adjusted. Traffic volume adjustment factor ε with the value of 1.2 was chosen. Therefore the average hourly volume used in the study was multiplied with adjustment factor ε = 1.2.

The loading was calculated according to the following formula for the loading factor:

$$L_f = \frac{Q_h \alpha}{C\varepsilon}, \quad (5)$$

where L_f – loading factor; Q_h – calculation hourly traffic volume, vph; C – total road capacity, vph; ε – traffic volume adjustment factor, ε = 1.2; α_1 – capacity adjustment factor for roadway with two lanes in one direction $\alpha_1 = 1.80$; α_2 – capacity adjustment factor for roadway with three lanes in one direction $\alpha_2 = 2.45$.

Measurements at night (1–4 a.m.) show that traffic volume in the street network is minimal in comparison with the rest of the day. Therefore the loading factor on arterials in these hours is 0.2. In the period from 11 p.m. to 1 a.m. the loading factor is 0.2–0.3. Traffic volume in urban streets increases dramatically in morning hours (6–8 a.m.) when the loading factor increases up to 0.5–0.6 and in turn the actual driving speed decreases. The loading factor amounts to 0.7–0.8 practically in all day time hours (7 a.m.–7 p.m.).

The determined relation between traffic volume and traffic flow density allows the forecasting of traffic volume on free-flow arterials according to the following formula:

– at regulation speed of 70 km/h with three lanes:

$$Q = -147.4 + 86.54C - 0.459C^2, \quad (6)$$

– at regulation speed of 70 km/h with two lanes:

$$Q = -196.0 + 91.61C - 0.798C^2. \quad (7)$$

A relationship between traffic volume and traffic flow density is another indicator that characterises traffic flow. Traffic flow theory postulates that with the increase of traffic volume the traffic flow density or the loading factor increases (He, Zhao 2013), as well. Fig. 5 shows the relation of traffic volume and traffic flow density on free-flow arterials.

3.2.3. Design speed and momentary speed

To evaluate the influence of design speed on existing speed the study included the measurements of driving speed on free-flow arterials with different regulation speed, number of lanes and different geometrical parameters with appropriate differing design speeds (Lazda, Smirnovs 2011).

The existing traffic measurements show that the main factor that determines the choice of driving speed is the traffic flow capacity (Duret *et al.* 2012). After the review of 95% of average momentary speed and design speeds at different loading factor on free-flow arterials a conclusion is made that the increase of design speeds above 80–90 km/h will not create any influence on the existing speed (Fig. 6).

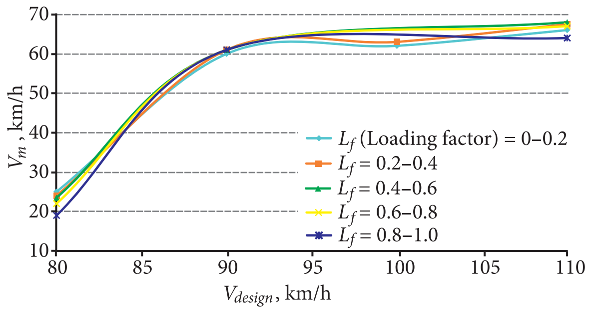

Fig. 6. Relation of 95% average momentary speed and design speed

4. Conclusions

1. The results of the study show that average speed on free-flow arterials amounts up to 50–60% of the design speed specified for the respective road. It has to be noted that congestion in peak hours in today's street network amounts to 12–14 hours, and the present study testifies that the speed that was used initially for designing the arterials streets is not implemented in approximately half of the day. Speed measurements in the street network show that design speeds or regulation speed, whatever they are, contribute neither to the increase of speeds nor to the time savings when driving a vehicle especially in daytime. As the study shows the main factor that influences the existing speed is the traffic flow density and the level of traffic load.

2. The design speed used in street design is defined as the driving speed of a single vehicle on road. However, with the constant increase of vehicle numbers single vehicles on streets could be seen only at night (10 p.m.–6 a.m.). The study shows that at present and in the future when the design speed is defined it is useful not to consider the driving of a single vehicle but to refer to traffic flow where traffic speed is depending on traffic flow density and limitations, speed limits and road accidents.

3. When analysing the data acquired on average momentary speeds it was concluded that the actual speeds on arterial streets rarely exceeded the design speeds for arterial streets. Such situations were observed only in 2% of all hours per day at the regulation speed of 50 km/h. However, at the regulation speed of 70 km/h the situations when driving speed exceeded the design speed occurred even much more rarely – only in 0.03%. Considering the above mentioned it is stated that significant capital investments needed to comply with the requirements set in normative documents for geometrical dimensions of arterial streets are inadequately high, as they would provide safety only for 0.03% of all drivers who in essence brutally violate the established maximum regulation speed on roads by more than 40 km/h.

4. The results of this study serve as the basis for determination of design regulation speed in urban areas on arterial streets with free traffic flow. This means that road parameters, such as radius of horizontal and vertical curves, lane width are reduced. Furthermore, the general road construction costs are reduced, while ensuring adequate level of traffic safety.

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Received 12 March 2012; accepted 7 May 2012